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HYDROLOGIC DESIGN OF SMALL FARM PONDS IN THE ROLLING PLAINS, CENTRAL PRAIRIES, AND WEST CROSS TIMBERS AREAS OF KANSAS, OKLAHOMA, AND TEXAS

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ACKNOWLEDGMENT

The data on rates and amounts of runoff from watersheds of various cover and land use used in this publication are those obtained from measurements made at the Red Plains Conservation Experiment Station at Guthrie, Okla., in cooperation with the Oklahoma Agricultural Experiment Station.[1] *Rainfall records were taken from the published reports of the United States Weather Bureau.*[2] *Evaporation records were obtained from measurements from evaporation pans made by the United States Weather Bureau, Bureau of Plant Industry, Oklahoma Experiment Station, and Texas Experiment Stations.*[3]

The authors are indebted to the personnel of the Oklahoma Agricultural Experiment Station and the Red Plains Conservation Experiment Station, and to the Regional Engineer and Zone Technicians of Region IV and members of the Washington Operations staff of the Soil Conservation Service for their advice and assistance in the selection of the area of applicability and of the manner in which the design data are presented.

The authors are also indebted to Miss Bernadette A. Reid who made the many detailed and monotonous computations, and to Miss Georgie A. Keller for her work in editing and assembling the manuscript.

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[1] SLOSSER, J. W. COMPILATION OF RAINFALL AND RUN-OFF FROM THE WATERSHEDS OF THE RED PLAINS CONSERVATION EXPERIMENT STATION, GUTHRIE, OKLAHOMA, 1931-38. U. S. Soil Conserv. Serv. Tech. Pub. 32, [approx. 200 pp.], illus. 1940. [Mimeographed.]

[2] CLIMATOLOGICAL DATA AND CLIMATIC SUMMARY OF THE UNITED STATES

[3] HORTON, R. E., and COE, J. S. COMPILATION AND SUMMARY OF THE EVAPORATION RECORDS OF THE BUREAU OF PLANT INDUSTRY, U. S. DEPARTMENT OF AGRICULTURE, 1921-32. U. S. Weather Bur. Mo. Weather Rev. 62: 77-89. 1934.

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HYDROLOGIC DESIGN OF SMALL FARM PONDS IN KANSAS, OKLAHOMA, AND TEXAS

The tables and procedures presented in this publication are to be used only in the design of small ponds of not more than 3 acre-feet capacity and only when the cost of construction does not exceed $500.

To determine the safe annual use U_{12} *(fig. 1)* that would be supplied by a pond for any value of maximum depth below spillway elevation D, the procedure is as follows:

1. Determine A, the area of the contributing watershed.
2. Determine a', the surface area of the pond at spillway level for $h_g = 6$ feet.
3. Multiply the area a' by the coefficients K found in *table 1* to obtain V_g for various values of h_g.
4. If the dam is to be constructed from material excavated from the reservoir site, fix the depth of excavation h_e and add to it corresponding values of h_g to obtain D, the maximum depth.
5. Estimate the cubic yards of excavation that will be required for each value of D and convert to acre-feet by multiplying by 0.000620. Add these values of V_e to corresponding values of V_g to obtain C, the total capacity.
6. Divide each value of C by the corresponding value of D to obtain a, the mean surface area.
7. From *table 2*, determine the safe annual use U_{12}, corresponding to each pair of D and a values.

The area of application is shown in *figure 2*.

EXAMPLE 1

Given: Cultivated 40-acre watershed in Kent County, Tex.

To find: Number of dairy cattle that could be watered from a reservoir having a maximum depth at spillway level D of 4 feet, 6 feet, and 8 feet.

Solution: A hand-level survey was made to determine the surface area of the pond at spillway level when h_g was equal to 6 feet. This was found to be 1.20 acres--that is, $a' = 1.20$ acres *(table 1)*. Auger borings at the reservoir site were made to determine the suitability of the soil as material for the construction of the dam and to disclose possible strata of underlying highly pervious material. As a result of these test borings, it was decided that the reservoir site was satisfactory and that the dam could be built from material excavated from the reservoir. The depth of excavation h_e would be kept at 2 feet.

Volume Above Natural Ground Surface

Since $D = h_g + h_e$ *(fig. 1)*, and since $h_e = 2$ feet, the values of h_g to be considered are 2 feet, 4 feet, and 6 feet. Coefficient K for these values of h_g, found from *table 1*, are 0.30, 0.92, and 2.47, respectively. Multiplying a' by these coefficients gives the following values:

$D = 4$ feet

$$a' \times K = V_g$$

(h_g = 2 feet)
(h_e = 2 feet)

1.20 acres x 0.30 = 0.360 acre-foot

$D = 6$ feet

(h_g = 4 feet)
(h_e = 2 feet)

1.20 acres x 0.92 = 1.104 acre-feet

$D = 8$ feet

(h_g = 6 feet)
(h_e = 2 feet)

1.20 acres x 2.47 = 2.964 acre-feet

Total Capacity

It was estimated that the excavation of 500 cubic yards would be necessary to supply the material for a dam with $D = 4$ feet. This would have to be increased to 800 cubic yards for $D = 6$ feet, and to 1,000 cubic yards for $D = 8$ feet. Multiplying these values by 0.000620 (factor for converting cubic yards to acre-feet) and adding V_g give the following:

$D = 4$ feet

(V_g = 0.360 acre-foot)

V_e = 500 cubic yards x 0.000620 = 0.310 acre-foot
V_g = .360 acre-foot
C = 0.670 acre-foot

$D = 6$ feet

(V_g = 1.104 acre-feet)

V_e = 800 cubic yards x 0.000620 = 0.496 acre-foot
V_g = 1.104 acre-feet
C = 1.600 acre-feet

$D = 8$ feet

(V_g = 2.964 acre-feet)

V_e = 1,000 cubic yards x 0.000620 = 0.620 acre-foot
V_g = 2.964 acre-feet
C = 3.584 acre-feet

Mean Surface Area

$\underline{D = 4 \text{ feet}}$

(C = 0.670 acre-foot) $\quad a = \frac{C}{D} = \frac{0.670}{4} = 0.17$ acre

$\underline{D = 6 \text{ feet}}$

(C = 1.600 acre-feet) $\quad a = \frac{C}{D} = \frac{1.600}{6} = 0.27$ acre

$\underline{D = 8 \text{ feet}}$

(C = 3.584 acre-feet) $\quad a = \frac{C}{D} = \frac{3.584}{8} = 0.45$ acre

Safe Annual Use

From *table 2* (Zone III cultivated watersheds) values for safe annual use were determined as follows:

$\underline{D = 4 \text{ feet}}$

(A = 40 acres)
(a = 0.17 acre)

Since no value of U_{12} is given in *table 2* for A = 40 acres, a = 0.17 acre, it is necessary to interpolate between table values given for A = 40 acres, a = 0.10 acre, and A = 40 acres, a = 0.30 acre.

Interpolating for $a = 0.17$ *acre*

$\underline{A = 40 \text{ acres}}$

	a = 0.10 acre;	U_{12} = 6 acre-inches
	a = .30 acre;	U_{12} = 1 acre-inch
Difference	= 0.20 acre;	5 acre-inches

$$\underline{U_{12} \text{ for } a = 0.17 \text{ acre}} = 6 \text{ acre-inches} - \left(\frac{0.17 - 0.10}{0.20} \times 5\right) = 6 - 1.8 = \underline{4 \text{ acre-inches}}$$

$\underline{D = 6 \text{ feet}}$

(A = 40 acres)
(a = 0.27 acre)

Interpolating for $a = 0.27$ *acre*

$\underline{A = 40 \text{ acres}}$

	a = 0.10 acre;	U_{12} = 8 acre-inches
	a = .30 acre;	U_{12} = 8 acre-inches
Difference	= 0.20 acre;	0 acre-inches

$$\underline{U_{12} \text{ for } a = 0.27 \text{ acre}} = 8 \text{ acre-inches} + \left(\frac{0.27 - 0.10}{0.20} \times 0\right) = \underline{8 \text{ acre-inches}}$$

D = 8 feet

(A = 40 acres)
(a = 0.45 acre)

Interpolating for a = *0.45 acre*

A = 40 acres

a = 0.30 acre; U_{12} = 16 acre-inches
a = .50 acre; U_{12} = 20 acre-inches
Difference = 0.20 acre; 4 acre-inches

$$U_{12} \text{ for } a = 0.45 \text{ acre} = 16 \text{ acre-inches} + \left(\frac{0.45 - 0.30}{0.20} \times 4\right) = 16 + 3 = 19 \text{ acre-inches}$$

Number of Dairy Cattle

Table 3 shows the annual water consumption per head of dairy cattle to be 0.269 acre-inch. Applying this figure to the above values of U_{12} gives the following:

D = 4 feet - U_{12} = 4 acre-inches

$$\text{Number of dairy cattle that could be watered} = \frac{4}{0.269} = 14 \text{ head}$$

D = 6 feet - U_{12} = 8 acre-inches

$$\text{Number of dairy cattle that could be watered} = \frac{8}{0.269} = 29 \text{ head}$$

D = 8 feet - U_{12} = 19 acre-inches

$$\text{Number of dairy cattle that could be watered} = \frac{19}{0.269} = 70 \text{ head}$$

EXAMPLE 11

Given: A 100-acre watershed of grass-pasture land located in Greer County, Okla.

To find: Whether or not the runoff from the above watershed would be sufficient to water 25 head of dairy cattle and if so, the depth of reservoir required.

Solution: It was decided that the material for the dam would be obtained from sources outside the reservoir site. Since there will be no excavation from the reservoir site, $h_g = D$ and $V_g = C$. A hand-level survey showed a' = 0.330 acre.

Total Capacity

Since depths less than 8 feet for the range of values of a given in *table 1* provide insufficient reservoir capacity to withstand the long periods of zero runoff and high evaporation rates experienced in Zone II, and since depths greater than 10 feet are outside the scope of this publication, it is only necessary to consider values of D = 8 feet and 10 feet.

Using coefficients given in *table 1*, the following values of C were determined:

$h_g = D = 8$ feet

($a' = 0.330$ acre) $0.330 \text{ acre} \times 5.06 = 1.670 \text{ acre-feet} = V_g = C$

$h_g = D = 10$ feet

($a' = 0.330$ acre) $0.330 \text{ acre} \times 9.05 = 2.986 \text{ acre-feet} = V_g = C$

Mean Surface Area

$D = 8$ feet

($C = 1.670$ acre-feet) $a = \frac{1.670}{8} = 0.21 \text{ acre}$

$D = 10$ feet

($C = 2.986$ acre-feet) $a = \frac{2.986}{10} = 0.30 \text{ acre}$

Safe Annual Use

From *table 2* (Zone II, pasture watersheds) values of safe annual use were determined as follows:

$D = 8$ feet

($A = 100$ acres)
($a = 0.21$ acre)

From the Table

$a = 0.10$ acre; $U_{12} = 1$ acre-inch
$a = .30$ acre; $U_{12} = 3$ acre-inches
Difference $= 0.20$ acre; 2 acre-inches

Interpolating for $a = 0.21$ acre

$$U_{12} = 1 \text{ acre-inch} + \left(\frac{0.21 - 0.10}{0.20} \times 2\right) = 1 + 1.1 = 2.1 \text{ acre-inches}$$

$D = 10$ feet

($A = 100$ acres)
($a = 0.30$ acre)

Direct from Table

$U_{12} = 7.5$ acre-inches

Table 3 shows the annual water consumption per head of dairy cattle to be 0.269 acre-inch. The water consumption of 25 head would then be 25 x 0.269 = 6.7 acre-inches. Comparing this amount with the values of safe annual use above, it is evident that a reservoir 10 feet deep would furnish the desired amount of water.

EXAMPLE III

Given: A 20-acre cultivated watershed, located in Logan County, Okla.

To find: The depth of reservoir required to water 100 head of beef and 20 head of dairy cattle.

Solution: As a result of an auger survey, it was decided to obtain the material for the dam from the reservoir site and to limit the value of h_e to 3 feet. The surface area a' was determined by a hand-level survey to be 0.80 acre.

Volume above Natural Ground Surface

Coefficients K corresponding to values of h_g = 3, 4, and 5 feet, were obtained from *table 1*, and multiplied by a' to obtain values of V_g.

D = 6 feet

(h_e = 3 feet)
(h_g = 3 feet)

$V_g = 0.80 \times 0.50 = \underline{0.40 \text{ acre-foot}}$

D = 7 feet

(h_e = 3 feet)
(h_g = 4 feet)

$V_g = 0.80 \times 0.92 = \underline{0.736 \text{ acre-foot}}$

D = 8 feet

(h_e = 3 feet)
(h_g = 5 feet)

$V_g = 0.80 \times 1.58 = \underline{1.264 \text{ acre-feet}}$

Total Capacity

D = 6 feet

(V_g = 0.40 acre-foot)

Estimated excavation = 300 cubic yards

$$\begin{aligned} V_e = 300 \times 0.000620 &= 0.186 \text{ acre-foot} \\ V_g &= .400 \text{ acre-foot} \\ \hline C &= 0.586 \text{ acre-foot} \end{aligned}$$

D = 7 feet

(V_g = 0.736 acre-foot)

Estimated excavation = 400 cubic yards

$$V_e = 400 \times 0.000620 = 0.248 \text{ acre-foot}$$
$$\underline{V_g \quad = \quad .736 \text{ acre-foot}}$$
$$C = 0.984 \text{ acre-foot}$$

D = 8 feet

(V_g = 1.264 acre-feet)

Estimated excavation = 500 cubic yards

$$V_e = 500 \times 0.000620 = 0.310 \text{ acre-foot}$$
$$\underline{V_g \quad = 1.264 \text{ acre-feet}}$$
$$C = 1.574 \text{ acre-feet}$$

Mean Surface Area

D = 6 feet

(C = 0.586 acre-foot)

$$\underline{a} = \frac{0.586}{6} = \underline{0.10 \text{ acre}}$$

D = 7 feet

(C = 0.984 acre-foot)

$$\underline{a} = \frac{0.984}{7} = \underline{0.14 \text{ acre}}$$

D = 8 feet

(C = 1.574 acre-feet)

$$\underline{a} = \frac{1.574}{8} = \underline{0.20 \text{ acre}}$$

Safe Annual Use

Values of safe annual use were determined from *table 2* (Zone I, cultivated watersheds:

D = 6 feet

(A = 20 acres)
(a = 0.10 acre)

$$\underline{U_{12}} = \underline{14 \text{ acre-inches}}$$

$D = 7$ feet

(A = 20 acres)
(a = 0.14 acre)

Values of U_{12} for $D = 7$ feet may be taken as the average of those given in the table for $D = 6$ feet and $D = 8$ feet.

Interpolating for a = 0.14 acre

A = 20 acres

$$a = 0.10 \text{ acre}; \quad U_{12} = \frac{14 + 20}{2} = 17.0 \text{ acre-inches}$$

$$a = .30 \text{ acre}; \quad U_{12} = \frac{42 + 59}{2} = 50.5 \text{ acre-inches}$$

Difference = 0.20 33.5 acre-inches

$$U_{12} \text{ for } a = 0.14 \text{ acre} = 17 + \left(\frac{0.14 - 0.10}{0.20} \times 33.5\right) = 24 \text{ acre-inches}$$

$D = 8$ feet

(A = 20 acres)
(a = 0.20 acre)

Interpolating for a = 0.20 acre

A = 20 acres

a = 0.10 acre; U_{12} = 20 acre-inches
a = .30 acre; U_{12} = 59 acre-inches

Difference = 0.20 acre; 39 acre-inches

$$U_{12} \text{ for } a = 0.20 \text{ acre} = 20 + \left(\frac{0.20 - 0.10}{0.20} \times 39\right) = 40 \text{ acre-inches}$$

Table 3 shows the annual water consumption per head of dairy cattle to be 0.269 acre-inch and that of beef cattle to be 0.134 acre-inch. The total annual consumption of 20 head of dairy and 100 head of beef cattle would, therefore, be:

$$0.269 \times 20 = 5.4 \text{ acre-inches}$$
$$+ \ .134 \times 100 = 13.4 \text{ acre-inches}$$

Total consumption = 18.8 or 19 acre-inches

Comparing this amount with the values of safe annual use, it is evident that a reservoir 7 feet deep would furnish the required amount of water.

TABLE 1.--*Values of* K *for use in formula* $V_g = a' K$ [1]

h_g in feet	2	3	4	5	6	7	8	10
Coefficient *K*	0.30	0.50	0.92	1.58	2.47	3.60	5.06	9.05

V_g = Volume between natural ground surface and spillway level in acre-feet

a' = Surface area of pond in acres when h_g is 6 feet

Example:

Given a' = 0.916 acre

Find V_g when h_g is 8 feet

Solution From the table, K = 5.06 when h_g is 8 feet

Substituting in the formula, V_g = 0.916 x 5.06 = 4.63 acre-feet

[1]Determined from area versus volume relationships developed by the authors.

TABLE 2.--*Values of safe annual use for selected values of* D, A, *and* a [1]

CULTIVATED WATERSHEDS

Depth D	Zone I[2]					Zone II[2]					Zone III[2]				
	Safe annual use in acre-inches					Safe annual use in acre-inches					Safe annual use in acre-inches				
	A = 10	A = 20	A = 30	A = 40	A = 50	A = 10	A = 20	A = 30	A = 40	A = 50	A = 10	A = 20	A = 30	A = 40	A = 50
feet	*Mean surface area = 0.1 acre*					*Mean surface area = 0.1 acre*					*Mean surface area = 0.1 acre*				
4	8	8	8	8	8	8	8	8	8	8	0	2	4	6	6
6	14	14	14	14	14	10	14	14	14	14	2	4	6	8	10
8	20	20	20	20	20	12	20	20	20	20	5	7	9	11	13
10	26	26	26	26	26	14	24	26	26	26	6	9	11	13	15
	Mean surface area = 0.3 acre					*Mean surface area = 0.3 acre*					*Mean surface area = 0.3 acre*				
4	23	25	25	25	25	5	15	22	22	22	0	0	0	1	3
6	28	42	42	42	42	0	20	30	40	40	0	4	5	8	10
8	33	59	61	61	61	0	26	36	46	56	0	0	14	16	18
10	39	64	79	79	79	0	31	41	51	61	0	0	19	23	25
	Mean surface area = 0.5 acre					*Mean surface area = 0.5 acre*					*Mean surface area = 0.5 acre*				
4	21	41	41	41	41	0	12	22	32	38	0	0	0	0	0
6	30	56	71	71	71	0	21	31	41	51	0	0	0	9	11
8	39	64	90	101	101	0	0	39	49	59	0	0	0	20	23
	Mean surface area = 0.7 acre					*Mean surface area = 0.7 acre*					*Mean surface area = 0.7 acre*				
4	20	45	58	58	58	0	0	19	29	39	0	0	0	0	0

PASTURE WATERSHEDS

Depth D	Zone I[2]				Zone II[2]					Zone III[2]				
	Safe annual use in acre-inches				Safe annual use in acre-inches					Safe annual use in acre-inches				
	A = 50	A = 100	A = 150	A = 200	A = 100	A = 200	A = 300	A = 400	A = 500	A = 100	A = 200	A = 300	A = 400	A = 500
feet	*Mean surface area = 0.1 acre*				*Mean surface area = 0.1 acre*					*Mean surface area = 0.1 acre*				
4	7	8	9	8	-	-	-	-	-	-	-	-	-	-
6	10	14	14	14	-	-	-	-	-	-	-	-	-	-
8	12	20	20	20	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5
10	14	22	26	26	2.5	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	Mean surface area = 0.3 acre				*Mean surface area = 0.3 acre*					*Mean surface area = 0.3 acre*				
4	7	14	22	25	-	-	-	-	-	-	-	-	-	-
6	14	23	30	38	-	-	-	-	-	-	-	-	-	-
8	21	29	36	44	3	3	3	3	3	0	0	1	1	1
10	27	36	44	51	7.5	7.5	7.5	7.5	7.5	0	0	5.5	5.5	5.5
	Mean surface area = 0.5 acre				*Mean surface area = 0.5 acre*					*Mean surface area = 0.5 acre*				
4	6	14	21	28	-	-	-	-	-	-	-	-	-	-
6	18	26	33	40	-	-	-	-	-	-	-	-	-	-
8	27	38	45	52	0	5	5	5	5	0	0	0	2	2
	Mean surface area = 0.7 acre													
4	6	14	21	28										

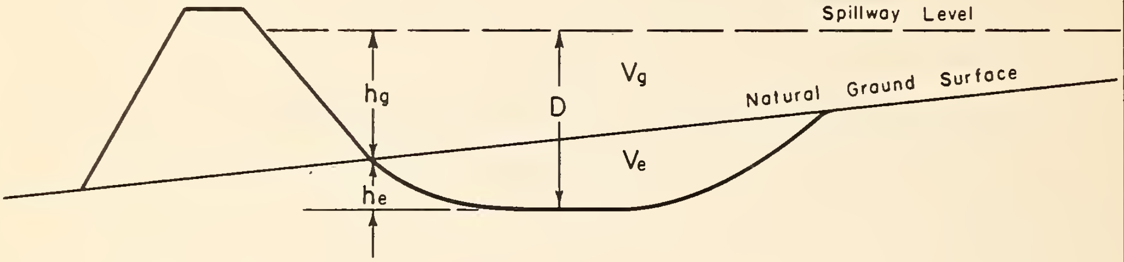
[1] Computed by the authors from measured values of rainfall, evaporation, and runoff.
[2] See area of application, figure 2.

TABLE 3.--*Approximate daily and annual water requirements of cattle and poultry*

Cattle or poultry	Unit	Water requirements Daily[1]	Annual
		gallons	*acre-inches*
Dairy cattle	1	20	0.269
Beef cattle	1	10	.134
Sheep	1	1	.013
Lambs	1	½	.007
Hogs	1	3	.010
Chickens	100	4	.054

[1]The above figures are averages of those recommended by Messrs. Henry and Morrison in their book ''Feeds and Feeding'' and those recommended by the Portland Cement Association for farm water supply.

Nomenclature



A = Drainage area in acres.

h_g = Height of spillway above natural ground, in feet, measured at the lowest point in the upstream toe of dam.

h_e = Depth of excavation below natural ground, in feet, measured at the lowest point in the upstream toe of dam.

D = Maximum depth of reservoir at spillway level, in feet.
$D = (h_g + h_e)$

V_g = Volume between natural ground surface and spillway level in acre-feet.

V_e = Volume of excavation in reservoir, in acre-feet.

C = Total reservoir capacity at spillway level, in acre-feet
$C = V_g + V_e$

a = Mean surface area of reservoir in acres. $a = C/D = \dfrac{V_g + V_e}{h_g + h_e}$

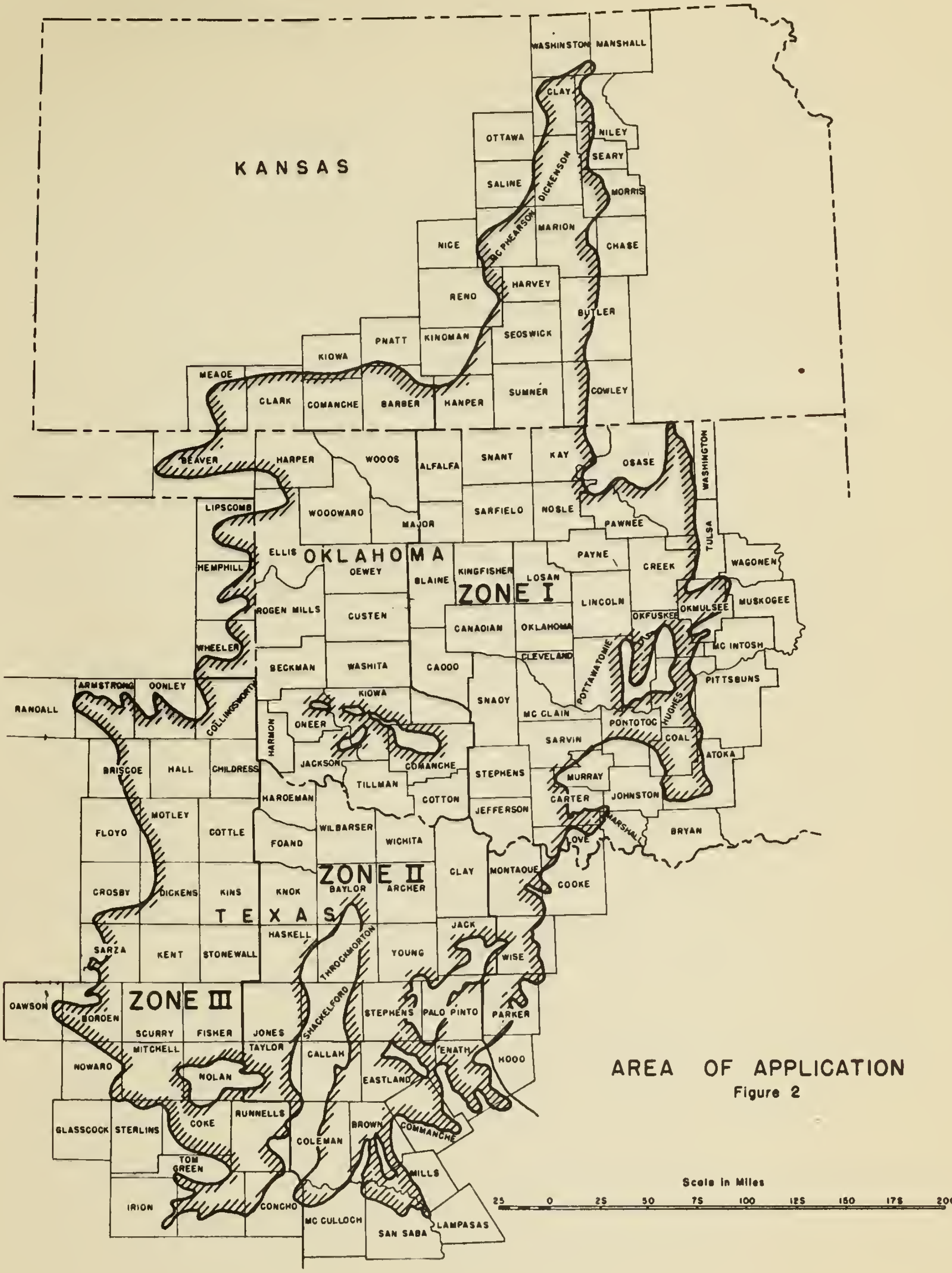
U = Water use in acre-inches. Subnumerals (U_6, U_{12} ---- U_{42}) indicate period of time in months.

E = Evaporation from surface of reservoir in inches.

P = Precipitation falling on surface of reservoir in inches.

r = Surface runoff from drainage area A, in inches.

Figure 1



AREA OF APPLICATION
Figure 2

SOIL CONSERVATION SERVICE, WASHINGTON, D. C., 1948